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Human Reaction Time Variability Changes from Low Intensity 3-Hz and 10-Hz Electric Fields: Interactions with Stimulus Pattern, Sex and Field Intensity

by

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ABSTRACT.- Eighty simple reaction times (RT) to the onset of a light stimulus during 40 min of 3 successive 10-min exposures to 3-Hz and 10-Hz electric field were measured for each of 70 human male and female subjects exposed to either 3 0 V/m, 0.3 V/m or sham field conditions. The electric fields were applied horizontally across the upper half of the subject who was seated in a Faraday cage during the experiment. Two methods of presenting the RT-stimulus (light onset) were used which incorporated rest or no rest periods. No significant differences in mean RT were noted between sexes, intensities or frequency changes. Significant sex, intensity and frequency interactions were found in the amount of RT variability as measured by the RT standard deviation of 20 trial blocks. However, the magnitude of the effects was quite small and may be of little practical importance.

INTRODUCTION

The presence of extremely low frequency (ELF) electromagnetic fields, waves and pulses in nature has been described by several authors (König, 1962; Reiter, 1964; Ormenyi, 1972). The physical characteristics of ELF electromagnetic phenomena and their effects on psychophysiological processes have been recently reviewed (Persinger, Ludwig and Ossenkopp, 1973).

Correlational studies first suggested that environmental ELF waves and pulses may influence human reaction time (König, 1962; Reiter, 1964; Ormenyi, 1972). Experimental replications of reaction time changes during application of external brain frequencies have been reported, but the effects seem very weak or subject to much individual variability. König (1962) noted that when a 1 V/m to 2 V/m vertically applied potential was time-varied at 3 Hz or 10 Hz, relative increases or decreases in RT, respectively, to the onset of light stimulus were recorded. Similarly, Hamer (1968) reported that human subjects exposed to different frequencies in a 2 Hz to 12 Hz band (4 V/m) also showed longer RTs with the lower frequencies rather than with the higher frequencies. According to König's (1971) diagrams of Hamer's data, 3 Hz fields were associated with longer reaction times than 8 Hz or 10 Hz fields.

Since the effects of externally applied ELF-brain frequency electric fields are quite small, we hypothesized that it was possible that more potent variables which influence human RT could mask much of the field effect by adding variability to the RT measure. Consequently, we decided to investigate the effects of 3 Hz and 10 Hz electric fields on human RT as a function of three variables which a priori, could be considered as among the most likely "masking" candidates: (1) presentation pattern of the RT stimulus, (2) sex of the subject and (3) intensity of the electric field. Since the electric field effect on RT is small, a measure

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of RT variability in addition to mean RT was also selected. Although it might not produce large shifts in the mean direction of an individual human RT system, the field could contribute to the system's stability by increasing or decreasing RT variability.

Experiment I

METHODS AND MATERIALS

SUBJECTS.- Thirty (30) female and 30 male university students (19-29 years of age) were selected as subjects. Since there were three field intensities used in this study, there were 10 male and 10 female subjects per field intensity condition. Participation in the experiments was voluntary and was offered as an option to other course work.

APPARATUS.- The electric fields were produced by applying electrical potentials horizontally from a Heath-Schlumberger (model EU-81A) function generator (sine-wave mode) across two 12-gauge steel plates (0.8 m x 0.8 m), separated by 0.8 m. The plates were held vertically on their 0.4 cm edges in a wooden reinforced frame 1.1 m x 0.9 m x 2.0 m. A single layer of galvanized-steel fly screen was wrapped and stapled around the frame. One end of the cage was made into a door so that when closed the cage was sealed by wire screen (Faraday cage). The steel plates, Faraday cage, and signal generator were connected to the standard 110 V ground cable.

Inside the cage were placed an upholstered wooden chair for the subject and a small table. A standard reaction time light source and response key apparatus was placed on the table. The time clock and trial initiator equipment were kept outside the cage so that neither they nor the experimenter could be seen by a subject.

PROCEDURE.- On the test day a subject was randomly allocated to one of the three intensity conditions which included "0" V/m (sham), 0.3 V/m or 3.0 V/m conditions, before entering the test area. The subject was then seated in the cage so that the upper half of the body was between the plates. The reaction time light source and response key apparatus were moved so that the subject's preferred hand could rest upon the latter. Instructions were given to the subject to press the key after the onset of the light as quickly and as uniformly as possible through the 40-min session. Four "warm-up" reaction time trials were then given.

There were 2 RT-stimulus (light onset) procedure patterns. In RT stimulus pattern I, 30 subjects (5 males and 5 females per intensity condition), were told that the light would appear 80 times during the next 40 min once every 15-40 sec following the previous presentation. This meant that they must be vigilant at all times in order to perform as quickly and as uniformly as possible. In RT pattern II, the other 30 subjects (5 males and 5 females per intensity condition) were told they would receive 80 stimulus presentations in 40 min but that there would be 8 blocks of 10 trials each with a 3-min rest period between blocks. These subjects were also informed that during the 2-min blocks of trials, the light would be presented once every 8 to 16 sec and the beginning or end of the block would be stated by the experimenter. During the rest period, subjects of RT pattern II were instructed to "relax, let your 'mind' wander, and let your 'thoughts' flow freely, but do not close your eyes for any length of time".

Light stimulus presentations for each pattern were given by the experimenter according to a predetermined sequence and were the same for each subject in a given pattern. The time-interval values for RT pattern I were multiples of 5 sec between 15-45 sec and had been randomly determined for 80 trials. The values

for RT pattern II were multiples of 2-3 sec between 8 to 16 sec and had been randomly determined for 80 trials.

Once the subject was comfortably seated and had been given the instructions and "warm-up trials", the signal generator (set at 3 Hz) was turned on 15 sec (RT pattern I) or 3 min before the first trial. When the generator was turned on, an electrical potential across the plates of 2.5 V RMS was applied for the 3.0 V/m groups and 0.25 V RMS was applied for the 0.3 V/m groups. In the sham procedure ("0" V/m) the generator was also turned on, but the power cable to the steel plates was not connected. The field frequency was varied, starting just before the first trial, every 10 min (20 trials) according to the following sequence 3 Hz/10 Hz/3 Hz/10 Hz. This meant that the subject was exposed to a constant frequency for 10 min. The change from 3 Hz to 10 Hz or visa versa required approximately 5 sec. In the sham ("0" V/m) group, the frequency selector was also turned, to "3 Hz" or "10 Hz" as added control procedure.

RT was recorded to the nearest 0.01 sec by one of three experimenters. At the end of the 40 min session, the voltage was monitored on the plates and the subject allowed to leave the Faraday cage. All subjects were tested between 14:00 h and 21:00 h between December 1972 and April 1973.

For data analysis, the mean reaction time for each 20 trials in the same frequency was averaged for each subject. The standard deviation (SD) for a given block of RTs was used as the measure of RT variability.

RESULTS

The mean reaction times (RTs) and standard deviations for the various groups according to sex (S), electric field intensity (E) and frequency change (Δf) for the 2 RT stimulus patterns, were calculated. A three-way analysis of variance (ANOVA) with the third factor (Δf) as the repeated measure, indicated no statistically significant changes between groups for either RT stimulus presentation pattern. Significant ($F = 19.31, 8.12$; $p < 0.001$) differences were noted on the repeated measure for all groups, but this difference reflected the gradual increase in mean RTs for all groups and did not differentiate E or S conditions.

The mean standard deviations which represent the RT variability for the various groups according to S, E, Δf, and stimulus pattern are shown in Figs. 1 and 2. For RT stimulus pattern I, a three-way ANOVA on S x E x Δf factors indicated statistically significant interactions between electric field intensity and frequency changes ($F = 3.73$; $p < 0.01$) as well as sex, between field intensity and frequency change ($F = 2.47$; $p < 0.05$). The ANOVA summary is shown in Table 1.

TABLE 1. Analysis of variance for reaction time standard deviations across sex, electric field intensity and repeated frequency changes for RT stimulus pattern I

Source	Source	DF	MS	F
	Bet subj	29.		
	Sex (S)	1.	6.86	2.21
	Intensity (E)	2.	0.53	0.17
	S x E	2.	3.91	1.26
	Subj W group	24.	3.11	
	Within subj	90.		
	Frequency (Δf)	3.	1.46	1.17
	S x Δf	3.	0.55	0.44
	E x Δf	6.	4.68	3.73**
	S x E x Δf	6.	3.10	2.47*
	Δf x subj W G	72.	1.25	

*) $p < 0.05$ **) $p < 0.01$

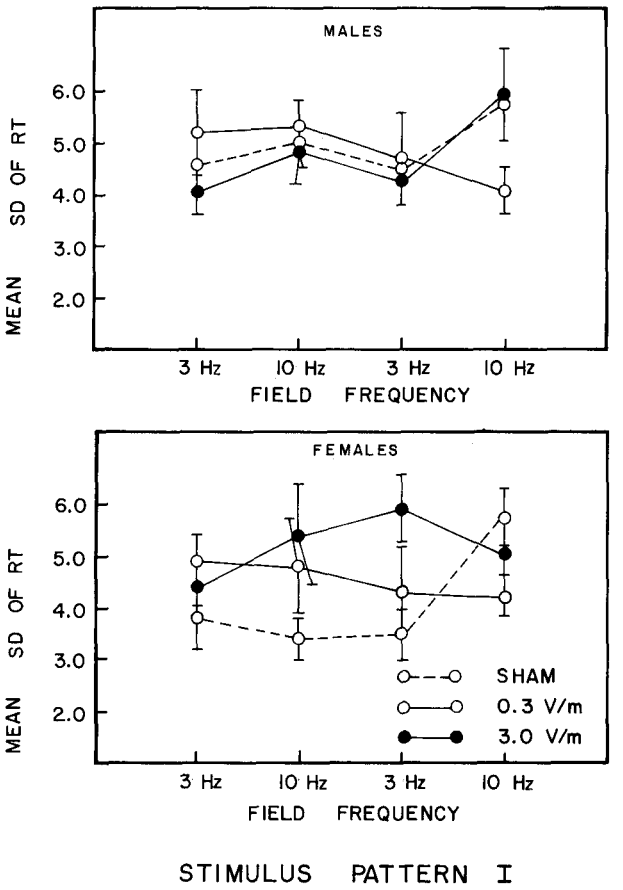

Fig. 1. RT stimulus pattern I. Changes in mean variability (standard deviations) of reaction times (RT) as a function of electric field frequency changes for male (n = 15, 5/intensity level) and female (n = 15, 5/intensity level) human subjects exposed to either sham, 0.3 V/m or 3.0 V/m conditions. Appropriate standard deviation range brackets are shown.

Independent t-tests between groups indicated that the 0.3 V/m males showed significantly less ($t = 4.02$; $p < 0.01$) RT variability during the last 10 Hz interval relative to the sham group. All other male intensity group differences were not significant. The 0.3 V/m female group exhibited significantly more RT variability during the first 3 Hz interval ($t = 2.70$; $p < 0.05$) but less ($t = 3.64$; $p < 0.01$) variability during the last 10 Hz interval relative to the sham group. The 3.0 V/m female group showed greater ($t = 3.30$; $p < 0.01$) RT variability than the sham group only on the second 3 Hz interval. Comparisons between the 0.3 V/m and 3.0 V/m groups were not significant. Correlated t-tests for each group across frequency changes indicated that the RT variability in the sham group during the last 10 min interval was significantly greater ($t = 3.68$; $p < 0.05$) than the previous intervals.

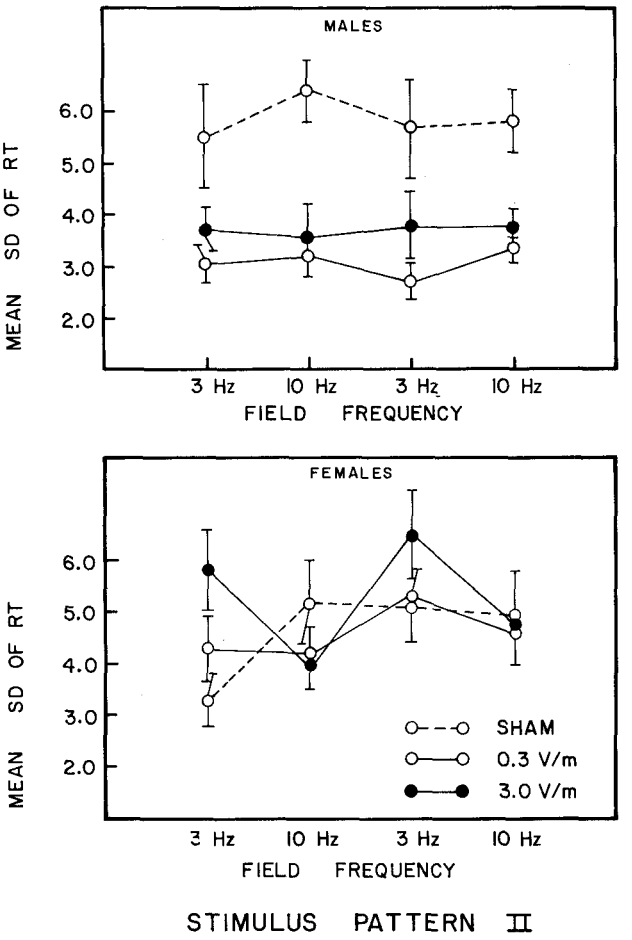

Fig. 2. RT stimulus pattern II. Changes in mean variability (standard deviations) of reaction times as a function of electric field frequency changes for male (n = 15, 5/intensity level) and female (n = 15, 5/intensity level) human subjects exposed to either sham, 0.3 V/m or 3.0 V/m conditions. Appropriate standard deviation range brackets are shown.

Significant decreases in RT variability occurred in the second 10 Hz and 3 Hz intervals relative to the first two intervals for the 0.3 V/m group ($t = 2.79, 3.56$; $p < 0.05$). No differences were apparent across frequency changes for the 3.0 V/m group. The last interval of the female sham group was also typified by greater RT variability than the first three intervals ($t = 3.03, 8.31, 8.26$; $p < 0.01$). No such changes were noted in the female 0.3 V/m group while the 3.0 V/m female subjects displayed significantly greater RT variability only between the second and first 3 Hz intervals ($t = 3.38$; $p < 0.05$).

For RT stimulus pattern II, analysis indicated that the mean standard deviations of RTs for groups exposed to different intensities were significantly different ($F = 4.46$; $p < 0.05$) and that a significant sex by intensity interaction ($F = 5.71$; $p < 0.01$) existed. The ANOVA summary is shown in Table 2.

TABLE 2. Analysis of variance for reaction time standard deviation across sex, electric field intensity and repeated frequency changes for RT stimulus pattern II

Source	DF	MS	F
Bet subj	29.		
Sex (S)	1.	14.63	3.44
Intensity (E)	2.	18.95	4.46*
S x E	2.	24.26	5.71**
Subj W group	24.	4.25	
Within subj	90.		
Frequency (Δf)	3.	1.43	0.83
S x Δ f	3.	3.44	2.00
E x Δ f	6.	2.85	1.65
S x E x Δ f	6.	1.01	0.59
Δf x subj W G	72.	1.72	

*) $p < 0.05$
**) $p < 0.01$

Independent t-tests between groups indicated that the 0 3 V/m male group demonstrated significantly less RT variability than the sham group across all 4 frequency changes ($t = 2.28, 3.37, 2.51, 2.77$; $p < 0$ 05). The 3.0 V/m male group showed statistically significant decreases in RT variability relative to the sham group only on the two 10 Hz field intervals ($t = 2.64, 2.40$; $p < 0$ 05). There were no significant differences between the 0.3 V/m and 3.0 V/m male groups. Female subjects from the 0.3 V/m group did not exhibit significant differences from the shams, while the 3.0 V/m group showed significantly more RT variability on the first 3-Hz presentation only ($t = 3.06$; $p < 0.01$). Correlated t-tests across frequency change intervals for stimulus pattern II groups were not statistically significant for the male subjects. Similarly, only the 3.0 V/m female group showed significant changes in RT variability between the first 10 Hz and 3 Hz field interval only ($t = 3.39$; $p < 0.05$).

DISCUSSION

The results of Experiment I indicated interactions between sex, field intensity and frequency changes for subjects exposed to RT stimulus pattern I. In this pattern, only the females exposed to the 3.0 V/m field intensity showed significant RT variability deviations from the sham group and this was most effectual during the 3 Hz intervals. Similar changes associated with 3 Hz, 3.0 V/m fields were noted for females responding to the RT stimulus pattern II situation. However, the intensity by frequency interaction indicated that: (1) the frequency fluctuations might have obscured a given frequency-intensity effect, or (2) intensity differences were compounding with purely serial effects from repeated RT trial (light) presentations. Consequently, a systematic replication was undertaken to compare the RT variability in situations where the intensity is held constant and the frequency is varied (as in Experiment I) with situations in which the frequency is held constant and the intensity is varied. This experiment was also performed as a reliability check of the results from Experiment I and to simulate the intensity variation designs of previous experimenters. In the constant frequency situation, 3 Hz was selected as the frequency since the most effective changes had been produced with this value. Field intensity sequences of 0.3 V/m, 3.0 V/m, 0.3 V/m and 3.0 V/m were selected. Since fatigue effects would become most confounding during the last two 0.3 V/m, 3.0 V/m periods, it was

predicted that an accentuated increase in RT variability (SDs) should be recorded during the first change from 3 Hz, 0.3 V/m to 3 Hz, 3.0 V/m.

Experiment II

METHOD

SUBJECTS.- Ten (10) female university students (19-40 years old) were selected as subjects. Participation in the experiments was voluntary and offered as an option to other course work.

APPARATUS AND PROCEDURE.- The electric field apparatus was the same as that used in Experiment I. Procedures followed the stimulus pattern I format of Experiment I, with the following exception. Each subject was exposed to four, 10 min, 20 trial blocks of 3 Hz, 10 Hz, 3 Hz and 10 Hz at 3.0 V/m and four 10 min, 20 trial blocks of 0.3 V/m, 3.0 V/m, 0.3 V/m and 3.0 V/m at 3 Hz. Half the subjects received the frequency changing sessions first and the intensity changing sessions second, while the other subjects received the sessions in a reversed order. Time between the two exposure sessions was not less than 2 days but not more than one week. All subjects were tested between July and August 1973.

RESULTS

The mean RTs for the frequency variation condition were 0.32, 0.32, 0.33 and 0.33 sec while the mean RTs for the intensity variation condition were 0.31, 0.32, 0.31 and 0.31 sec respectively. Standard deviations averaged 0.02 sec. ANOVA indicated no significant differences. Mean RT standard deviations are presented in Fig. 3.

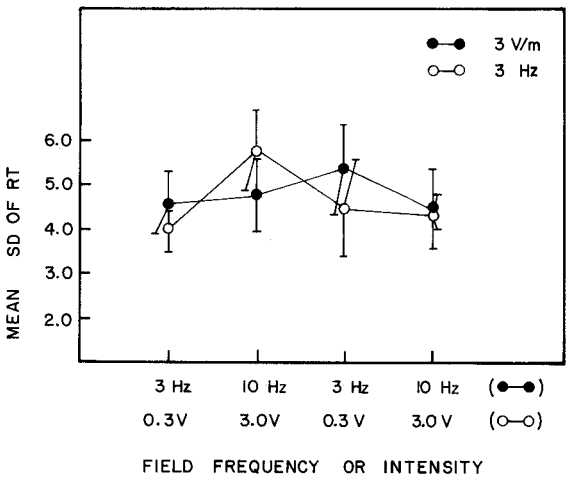

Fig. 3. RT stimulus pattern I. Mean changes in variability of reaction times as a function of changes in electric field frequency with a constant intensity (3.0 V/m) and of changes in electric field intensity with a constant frequency (3 Hz) for 10 female subjects. Appropriate standard deviation range brackets are shown.

Mean RT standard deviations for the frequency variation condition were 0.046, 0.047, 0.054 and 0.045 sec and 0.040, 0.058, 0.045 and 0.044 sec for the intensity variation condition. A condition by repeated measure (intensity or frequency) ANOVA indicated no statistically significant differences between conditions, but significant differences across frequency or intensity changes ($F = 3.20$; $p < 0.05$) and a condition by frequency or intensity change interaction ($F = 3.15$; $p < 0.05$). A summary of the ANOVA is shown in Table 3.

TABLE 3. Summary of ANOVA for groups exposed to changing intensity and changing frequency electric field conditions

Source of variation	DF	MS	F
Between subjects	19		
A (E or f constant)	1	0.30	0.04
Subjects within groups	18	7.79	
Within subjects	60		
B (Δf or ΔE)	3	3.73	3.20*
A x B interaction	3	3.67	3.15*
B x subj within groups	54	1.16	

*) $p < 0.05$

Correlated t-tests indicated that only the intensity variation group showed significant differences across intensity variations whereas the frequency variation group did not show significant differences across frequency changes, although as in Experiment I the second 3 Hz interval showed the greatest RT variability ($t = 2.00$; $0.10 > p > 0.05$). The marked increase in RT variability for the intensity variation group during the first 3.0 V/m interval was significantly different from the first 0.3 V/m interval ($t = 3.42$; $p < 0.01$) and the second 0.3 V/m and 3.0 V/m intervals ($t = 2.36$, 2.44, respectively; $p < 0.05$).

DISCUSSION

The results of the present studies indicate that 3 Hz and 10 Hz electric fields applied during 10 min intervals at 3.0 V/m or 0.3 V/m do not influence mean reaction time to the onset of a light stimulus. However, weak electric field effects were noted when the amount of RT variation was analyzed. The interactions of RT variability with RT stimulus pattern, sex and field intensity support the initial hypothesis that the electric field effects are very weak and can be obscured by other more potent controlling variables. Despite complex interactions, the following conclusions can be made: (1) female subjects show different RT variability patterns than male subjects as a function of field intensity and frequency change; (2) male and female groups exposed to different intensities show different patterns of RT variability to the same frequency changes; (3) female subjects show their greatest RT variability when exposed to the 3 Hz, 3.0 V/m situation; (4) the pattern of RT stimulus presentation during electric field exposure has a marked influence on RT variability patterns; (5) the change in RT variability occurs within 10 min of field exposure.

The variables responsible for the differences in RT variability for male and female subjects are not apparent from this study. Differences in response patterns between sexes exposed to the same ELF electromagnetic fields are predictable from the statement of Ludwig and Mecke (1968). They suggested that field responsiveness would vary as a function of autonomic lability and ortho-parasym-

pathetic dominance, factors which are heavily sex dependent. Vagotonic and sympathotonic dominance are known to be correlated with alpha frequency range (Gellhorn and Loofbourrow, 1963). The range of dominant biofrequency spectra would theoretically influence the probability of resonance interaction with applied fields (Persinger, 1974).

Stimulus procedures, sex of subject and different intensities can add variance to electric field effects on reaction time. These variables should be taken into consideration or, alternatively, experimental procedures can be implemented to increase the field effect in nature-like conditions. It seems highly unlikely that field strengths and frequencies used in this study would have significant influences upon human subjects under normal conditions. However, brain susceptibility to either naturally or artificially applied brain-frequency electromagnetic fields could be increased under conditions where the brain becomes "electrically plastic" and capable of being driven by weak external resonance-frequency forces. At least one experiment (Gavalas et al., 1970) indicates that weak ELF fields may influence EEG power spectra.

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